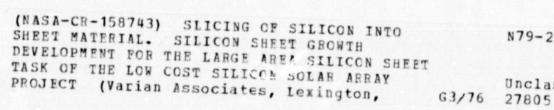
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Silicon Sheet Growth Development for the Large Area Silicon Sheet Task of the Low Cost Silicon Solar Array Project

ELEVENIH QUARTERLY REPORT

By

J. R. FLEMING

Silicon Sheet Growth Development for the Large Area Silicon Sheet Task of the Low Cost Silicon Solar Array Project

ELEVENTH QUARTERLY REPORT

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J. R. FLEMING

January 20, 1979

Reporting Period October 28, 1978 to December 29, 1978

JPL Contract No. 954374

Varian Associates
Lexington Vacuum Division
121 Hartwell Avenue
Lexington, Massachusetts 02173

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S-100-Q11

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1.0 SUMMARY

Tests on mineral oil slurries have shown that the potential for workability and low cost is present. However, slurries tested to date which had sufficient lubricity have exhibited wafer breakage problems near the end of the run for as-yet unknown reasons.

The first test of the large prototype saw under cutting force control was largely successful in that the controller worked perfectly. Unfortunately a technique error (excessive stroke shortening) caused blade breakage and low yield.

The latest run of the large saw pointed up the fact that an indication of end-of-stroke vertical motion, or "bounce", is necessary. A circuit to provide such indication has been fabricated and installed. Preliminary tests show it to be excessively noise sensitive, and we are now working on grounding and shielding to reduce this sensitivity.

2.0 PROGRESS

2.1 Slurry Tests

Previous tests with a slurry fluid of low viscosity (100 SUS) mineral oil with lard oil lubricity additive mixed 5:1 by volume have shown mixed results. The drag force problem has been eliminated. Cutting times have been made reasonable by increasing the amount of abrasive, which should not be necessary in newer saws due to decreased abrasive "laydown" in the return path to the slurry bucket. Yield has been poor, and wafer quality has ranged from poor to excellent.

In Test #2-3-28, we reduced the proportion of lard oil to 40:1, which is recommended for many applications. If the large amount of lard oil was causing the problem, this reduction should allow the yield to be raised. All conditions were standard except the abrasive mix, which was increased to 0.48 kg/l (4 lg/gal) as in Test #2-3-27.

Unfortunately, there was too little lard oil to prevent the drag force problem, and several fuses blew. At 41 mm (1.6 in.) cut depth the mineral oil/lard oil ratio was decreased to 20:1 by adding lard oil. No more fuses blew, but wafer breakage started almost immediately.

Final yield was 66%. Cutting time was 38.3 hours, bow was 198 μ m (.008 in.) and taper was 87 μ m (.0035 in.).

We conclude that mineral oil slurries with libricity additives seem workable, but lard oil may not be the right additive. We will test other additives.

2.2 Prototype Tests

In Test #2-7-05, we first tested the feed force controller. This controller uses the fact that the ingot is mounted on a spring loaded table, much like the bounce fixture. The deflection of this table is sensed by an LVDT, and the resulting signal is

compared to a reference signal which is proportional to the desired total load. Depending on the results of the comparison, the motor driving the bladehead into the work is sped up, slowed down, or kept at constant speed. To avoid instability, the signal to the motor is the integral of the "error" or difference between the LVDT and reference signals.

The run started very well. Cutting rate was high, so we increased the load to full load very slowly.

About 1/3 of the way through the run, a banging noise was noticed. Hindsight shows that this was due to a worn bearing. The bearing had accumulated slurry due to insufficient slurry bucket sealing.

At the time of the run, we could not tear down the machine sufficiently to discover the worn bearing without terminating the run. It seemed (wrongly) that the noise was something banging against the inside of the slurry bucket, and that shortening the stroke reduced the noise for a while.

The operator continually shortened the stroke until the final stroke was about 50 mm (2 in.). Since the volume of blades worn away is roughly constant, this short stroke caused excessive blade height wear. With about 2.5 mm (.1 in.) of ingot left to be cut, blades started breaking. By the time the blades were sufficiently into the submount to remove the wafers, enough blades had broken to make the final yield 31%.

Cutting time was long, 41.6 hours, again because of the short stroke. NTV was 105 μm (.004 in.) and bow was 324 μm (.013 in.). These were also probably a result of excessive blade wear.

In spite of the problems, the feed force controller worked very well, and we still feel that our problems are associated with learning how to use the prototype.

2.3 Other Progress

The prototype tests have pointed up the necessity of displaying the bounce to the operator so that good decisions can be made as to when to shorten the stroke. The information is already contained in the LVDT signal. A peak-to-peak detector circuit has been designed and built, and is now being installed. Since the frequencies are low (about 0.1 - 1 Hz), time constants must be long, so impedances must be high, which makes the circuit very noise sensitive.

3.0 PROBLEMS

No significant problems occurred during the reporting period.

4.0 PLANS

Plans for the next quarter include:

- Further testing of mineral oil slurry vehicles with various additives.
- "Fine Tuning" and testing of the bounce indicator circuit on the large prototype.
- Testing the large prototype under both baseline and more stringent conditions.
- Tests and operation of the 686 bounce fixture.
- Continued investigation of abrasive recycling.

SLICING TEST SUMMARY

PARAMETER TE	ST 2-3-28	2-7-05	
Material	Si	Si	
	(mm) 100 dia	100 dia	
Area/Slice (cm ²) 78.5	78.5	
Blade Thickness	(mm) 0.15	0.15	
Spacer Thickness	(mm) 0.36	0.36	
Blade Height	(mm) 6.35	6.35	
Number of Blades	150	975	
Load (gram/bl	ade) 85	85	
Sliding Speed (cm/	sec) 58.16		
Abrasive (type/grit s	ize) SiC/#600	SiC/#600	
Oil Volume (lite	ers) 7.6	37.9	
Mix (kg/li	ter) 0.48	0.36	
Slice Thickness	(mm) 0.278	0.285	
Kerf Width	(mm) 0.230	0.224	
Abrasive Kerf Loss	(mm) 0.080	0.074	
Cutting Time (ho	urs) 38.33	41.58	
Efficiency (full to	est) 0.954		
(typi	cal) 1.293		
(maxi	mum) 1.686		
Abrasion Rate (full t	est) 0.047	0.042	
$(cm^3/hr/bl)$ (typi	cal) 0.064		
(maxi	mum) 0.083		
Productivity (full t	est) 2.049	1.889	
(cm ² /hr/bl) (typi	cal) 2.784		
(maxi	mum) 3.611		
Yield	66%	31%	
Slice Taper	(mm) 0.087	0.105	
Slice Bow	(mm) 0.099	0.162	
Abrasive Utilization (cm		125.44	
Oil Utilization (cm ³ /li	ter) 35.63	45.16	
Blade Wear Ratio (cm ³ /	cm ³) 0.042		

MAN-HOURS AND COSTS (PHASE II)

During the reporting period of October 28, 1978 to December 29, 1978, total man-hours were 706.5 hours and total costs were \$29,458. Previous expenditures were 13192.7 hours and \$588,030. As of December 29, 1978, total program man-hours were 13899.2 hours and total program costs were \$617,488.

Varian Associates/Lexington Vacuum Division JPL Contract 954374 Starting Date: 1/9/76 (I) 5/19/77 (II)

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PROJECT MILESTONES				1	977									197	8								197	79		
(PHASE II)	М	J	J	А	S	0	N	D	Ü	F	М	Α	М	J	J	Α	S	0	N	D	J	F	М	Α	М	J
Task I Low Cost Oil Analysis of Suspension Oils Survey Low Cost Oils Test Suspension Qualities Fabricate/Purchase Oils Task 2 Cutting Tests - Slurry Test Suspension Oils Test Oil Mixtures Test Abrasive Size Mixes Lifetime Enhancement Task 3 Evaluate Degradation SEM Analysis of Abrasive/ Silicon Debris Reclamation of Oil/Abrasive Analyze Lifetime Effects Identify Low Cost System Task 4 Test Low Cost Slurry Evaluate Cutting Lifetime Evaluate Impact on Accuracy Rate, Wafer Yield, etc.	9. 9.			7			7			7						7					J .	•	M	A	M	

SCH 6/15/77 Updated 1/20/79 Varian Associates/Lexington Vacuum Division JPL Contract 954374 Starting Date: 1/9/76 (I) 5/19/77 (II) Phase II Program Plan Page 2 of 8

PROJECT MILESTONES				1	97	7								197	78								197	79		
(PHASE II)	М	J	J	Α	S	0	N	D	J	F	М	Α	М	J	J	Α	S	0	N	D	J	F	М	A	М	J
BLADES																										
Task 5 Low Cost Blades	5	-	-	-	7	7_	-	-		wage.	7.0	-	-	-	_	_	_		_	_						
Order Low Cost Materials	1	7																								
Analyze Tolerance Req'mts	1	_		-	W .																					
Cutting Tests-L/C Materials		9	2	_	7	7		_	-		-	-	-	-	-	_	_	_	_	_						
Specify Biade Tolerances					7	7					*															
Task 6 Alignment Device	2	_		_	_		_	7	7	_	-	_	-	-	-				-4							
Design/Fabricate Prototype	2	_	_	7																						
Blade Alignment Measurement	9	•		_	_		-	7_	-	_	-	_		-	-		_	_	y							
Cutting Tests			•	_	_	7	7	_	-	_	_		_	-	-		_		_7							İ
Demonstrate Improvements (Accuracy, Thickness, Rate)								7	7																	
Task 7 Blade Hardness							•		2_	_	_	_	_	7	7_	_3										
Order Blade Stock							-	1	7					-												
Cutting Tests									2	_		_	7	7	_	J										
Wafer Accuracy Blade Wear Characterization									•					7	_	_5										
Specify Blade Hardness	1													4	7											
Task 8 Laboratory Saw	2			_	_			_	-									7	7 5							
Design/Fabricate(1-10 Blade	2		_		7	7		_	-		y						1									
Test Effect of Blade Size					(_		7																
Specify Blade Size									4	7																1
Supporting Tests - Misc.									ф									7	7							

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PROJECT MILESTONES				19	77									19	78								197	79		
(PHASE II)	М	J	J	Α	S	0	N	D	J	F	М	Α	М	J	J	Α	S	0	N	D	J	F	М	Α	М	
Task 9 Work Moving Drive Conceptual Design Analysis/Specifications Design Purchased Items Task 10 Feed Mechanism Conceptual Design Analysis/Specifications Design Purchased Items Task 11 Bladehead Structural Analysis Specifications Design Task 12 Blade Tensioning Conceptual Design	M Q Q		3	A	S	0		7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7					М.	J	3	A	S	0	N	D	J	F	М	A	М	
Analysis/Specifications Design Fabrication	1						-	-	2.5	7	_	=	7													

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Starting Date: 1/9/76 (I) 5/19/77 (II)

Phase II Program Plan

PROJECT MILESTONES				15	77	1								19	78								197	79		
(PHASE II)	М	J	J	А	S	0	N	D	J	F	М	А	М	J	j	A	S	0	N	D	J	F	М	Α	М	,
Task 13 Cycle Control Cutting Force Sensor Prototype Design Task 14 Misc. Design Slurry Feed Lubrication Work Mounting Task 15 Prototype Fabrication Assembly Testing - Preliminary Task 16 Test & Revise Cutting Tests Revisions Add Alignment Device Demonstrate L/C Slicing Wafer Characterization							7	7	7	,			7		2				7.5		777				,	

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PROJECT MILESTONES	L			19	77								- 1	197	8								197	9		
(PHASE II)	М	J	J	А	S	0	N	D	J	F	М	Α	М	J	J	Α	S	0	N	D	J	F	М	A	М	J
ROCESS INTERFACE																										
Task 17 Comp. Cost Analysis	0	_		_	-	_	-	-	-	-		_	_	_	_	_								7	7	
Identify Cost Elements	6	-		1																						
Baseline Cost Analysis	6	-	_				-	-	1																	
Update - MS Slicing			4	2_	-	-	_				1				_	-								4	7	
Other Slicing Techniques	1					0	_						Z	7												
Task 18 Cell Fabrication			9	_	-		-	_			-52				-				_					4	7	
Fabricate Standard Slices			9	2				A	1		¢	2												4	7	
Fabricate Prepared Wafers				9								7	7	7												
Evaluate V _{oc} , I _{sc} , FF, eff.				9	-	-	+	-	-	_	-	_	_		_		_	_	-	_		-	4	4	7	
Task 19 Surface Preparation			2	-	_		1	1	_				- 6	7	y											
Chem/Mech. Damage Removal		9	2	_	_		-	V	-	-	7															
Combined Removal Techniques							0	4	1				_ 7	7								-				
Evaluate Cell Performance				ф		_	1	1				_	5 4	7	Y							-				
Damage Characterization				ф								4	7											1		
Optimize Removal Techniques									ф				7	7								1				
Task 20 Mech. Wafer Testing	2						女								P	-						1	1			
Design/Fabricate 4 Point Bending Fixture	2		V	,				-			1												1	1		
Background Analysis	0		_		7					1				1												
Test Wafer Strength			ф					-						-			-					1	1	1	1	
Specify Handling/Cutting Limitations of Wafers			1	1	4		4	1			1					1							1	1		19.00

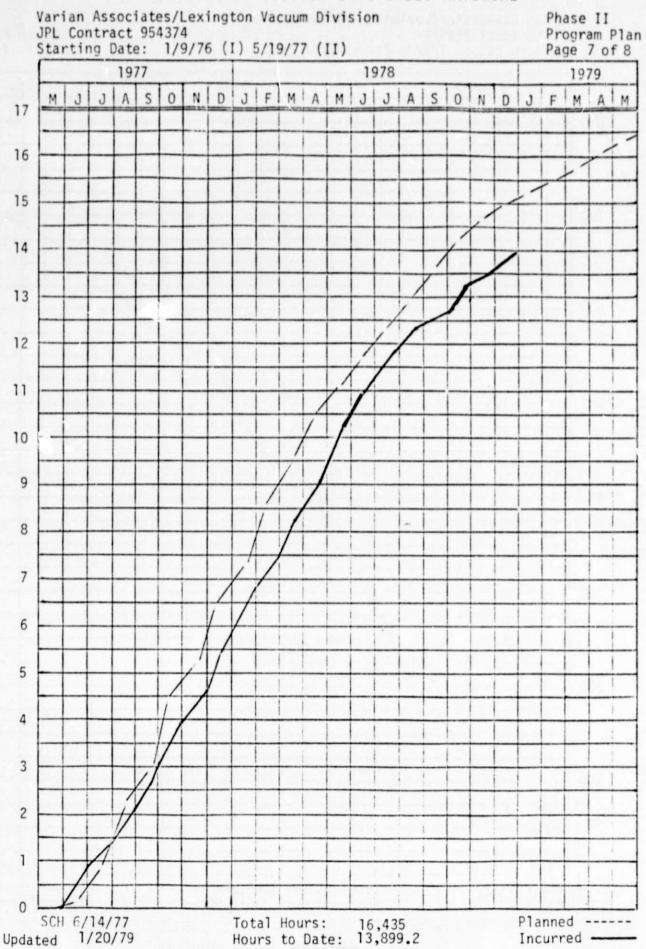
SCH 6/15/77 Updated 1/20/79

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Starting Date: 1/9/76 (I) 5/19/77 (II)

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PROJECT MILESTONES				19	77								1	978								Г		10	979		
(PHASE II)	М	J	J	Α	S	0	N	D	J	F	М	Α	М	J	J	A	S	0	N	N	D	J	F	M	A	М	J
REPORTS																		-	1		_	-	=	-	-	-	-
Financial Package		A	V	-	V	V	V	V	V	7	8	V	v	V	A	-	-	-	-	-	v	7	7	D	7	7	0
Monthly Technical Progress	1	V			V		V	V	ľ	A			V	V				•	1	V	•	_	V	V	\v	V	\v
Quarterly Technical Progress		7	7		4	,			7			7		1	,	ľ	1		•	•	٦,	,	V	14	,	V	
Interim Summary)			
Draft Final Report																											,
Final Report																										1	1
TRAVEL																											
Project Integration Meetings			4	7		4	7-	,	4	7	-		7	1	, ,	7		7	,	.	-	4	7		A	,	
MAJOR EQUIPMENT												1		I	Ì						1	1			V		
2 Test Saws	1	7												-	1												
Wafer Measuring Station	1	7			-									1	1					1							
Silicon Purchases		4	,		-			4	-					4	,	-				1	-						
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DIRECT LABOR (HOURS 000 OMITTED)

PROGRAM LABOR SUMMARY

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